Electronic Supplementary Material

Validation of the "Langur" snowpack model

The model has been validated against a random sample of snowpack measurements throughout YNP by Watson et al. (2009). In the 2007-08 winter we also took field measurements of SWE at 41 sites to validate the Langur predictions for our study sites. We assessed percent forest canopy cover and the average height of vegetative ground cover (e.g. grasses and forbs) at each site, as these could also potentially influence aspen sucker survival. Predicted SWE across sites was significantly correlated with observed SWE measured in the field ($R = 0.66$, $P < 0.01$; one outlier site removed). Site-specific maximum SWE was significantly correlated with elevation in the winters of 2007-08 ($R = 0.70$, $P < 0.01$) and 2008-09 ($R = 0.67$, $P < 0.01$).

Predictor variables for models from camera trap data

We used predicted SWE (from the Langur model described above) and sex (mature males versus females and immature males combined) as predictor variables for elk visitation to sites; the latter is based on the grounds that, following heavy energy expenditures during the autumn rut, adult males could respond differently to potential food resources or stressors (cf. Creel & Christianson 2009). Mature males were distinguished in the photographs by their branched antlers, while immature males had unbranched antlers or none at all. We included both a *male* main effect and a *SWE × male* interaction term in the initial models, and selected final variables for inclusion using backward-elimination stepwise logistic regression with a clustered variance design (Cleves et al. 2010). The final daily visitation model from backward-elimination stepwise multiple logistic regression was (also see Figure S1):

$$\hat{y} = \frac{exp(-1.569 - 0.147 * SWE - 0.765 * male)}{1 + exp(-1.569 - 0.147 * SWE - 0.765 * male)}$$

Snowpack decline in the Yellowstone Ecosystem

Significant declines in northern Yellowstone winter snowpack have been observed directly for 1948-2003 (Wilmers & Getz 2005); we complemented this with an analysis of an index of winter snowpack over the entire twentieth century. We examined long-term snowpack dynamics in the Yellowstone Ecosystem using a time series of the Palmer Drought Severity Index (PDSI) averaged from November-May. PDSI data came from the National Climatic Data Center of the National Oceanic and Atmospheric Administration for Division 1 ("Yellowstone Drainage") of Wyoming, accessed at http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#.

To assess historical change in snowpack conditions in the Yellowstone Ecosystem, we analyzed trends in an index of snowpack, the November-May average Palmer Drought Severity Index (PDSI) for the Yellowstone Drainage in Wyoming. Winter PDSI in this region declined (indicating drier conditions) significantly from 1895-2008 (slope = -0.06, R^2 = 0.31, $P < 0.01$; Figure S2).

Additional discussion of altered snowpack as a mechanism of climate change

Changing snowpack conditions could alter species interactions across mid- and high-latitude systems. Snow is a strong abiotic driver of ecological conditions in these regions (Jones *et al.* 2001), and changes in winter conditions may be a critical facet of climate change (Kreyling 2010). For example, muskoxen (*Ovibos moschatus*) spatial distribution and social organization in Greenland respond to changes in plant productivity driven by variation in snow (Forchhammer *et al.* 2005). Moreover, the expansion of elk winter distribution in Arizona in response to two-decade declines in snowpack may be responsible for strong increases in browsing levels and local reduction in deciduous tree density (Martin 2007).

Supplementary literature cited

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Wilmers, C. C. & Getz, W. M. 2005 Gray wolves as climate change buffers in Yellowstone. *PLoS Biology* **3**, e92.

Table S1: Model selection for the influence of snow water equivalent (*SWE*), elevation ("*Elev*"; m), forest cover ("*Forest*"; %), height of the ground vegetation ("*Ground*"; cm), and *predation risk* (from Kauffman et al. 2007) on annual aspen sucker survival. All models also included *sucker height* (cm; see Table 1 in main text) as a predictor variable.

Model	AIC	ΔAIC	Akaike weight
SWE	1032.68	0.00	0.996
Elev	1046.82	14.14	0.001
Forest	1051.26	18.59	0.000
Ground	1051.41	18.74	0.000
Predation risk	1051.28	18.61	0.000
Elev + Forest	1046.12	13.44	0.001
Elev + Ground	1047.03	14.36	0.001
Forest + Ground	1053.26	20.58	0.000
Elev + Forest + Ground	1046.38	13.71	0.001

Table S2: Model selection for the influence of snow water equivalent (*SWE*) versus *predation risk* (from Kauffman et al. 2007) on aspen browsing rate (winter height change). Both models also included *sucker height* (cm; see Table 1 in main text) as a predictor variable.

Model	AIC	ΔAIC	Akaike weight
SWE	1595.52	0.00	0.768
Predation risk	1597.91	2.39	0.232

Figure S1: Visitation to aspen stands by female and immature male elk (A) and mature male elk (B) versus weekly-averaged snow water equivalent (SWE). Predicted probability of daily visitation to aspen stands by female and immature male elk (C) and mature male elk (D) versus predicted daily SWE, with 95% confidence limits.

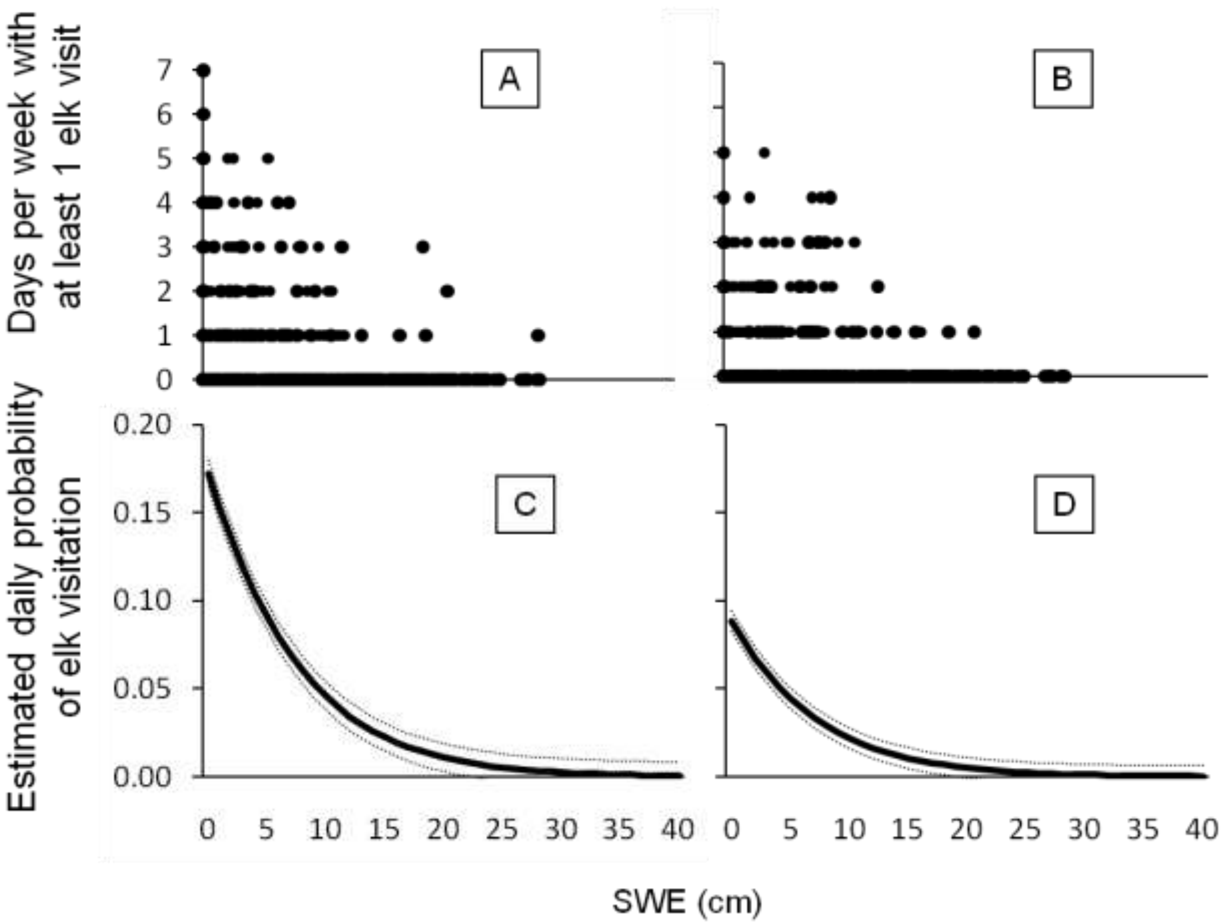

Figure S2: Annual (dashed lines and open circles) and 5-year running average (solid line) Nov-May Palmer Drought Severity Index (PDSI) for the Yellowstone River Drainage in Wyoming.